ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Physics Procedia 37 (2012) 483 – 490

Physics Procedia

TIPP 2011 – Technology and Instrumentation in Particle Physics 2011

A novel temperature monitoring sensor for gas-based detectors in large HEP experiments

L. Benussi[a], S. Bianco[a], M. A. Caponero[a,b,1]*, S. Colafranceschi[a], M. Ferrini[a,c], F. Felli[a,c], L. Passamonti[a], D. Pierluigi[a], A. Polimadei[b], A. Russo[a], G. Saviano[a,c], C. Vendittozzi[c]

[a]*Istituto Nazionale Fisica Nucleare, Laboratori Nazionali Frascati, via E. Fermi 40, 00044 Frascati, Rome, Italy*
[b]*Centro Ricerche ENEA Frascati, via E. Fermi 45, 00044 Frascati, Rome, Italy*
[c]*Dept. ICMA, University "La Sapienza", via Eudossiana 18, 00184 Rome, Italy*

Abstract

Gaseous detectors are commonly used in HEP (High Energy Physics) experiments to reconstruct the track of elementary particles. They are often made by a very large number of chambers with relatively small individual volume, arranged in thick layers placed approximately all around the vertex of the experiment in order to detect elementary particles produced in any direction. The large volume of gas inside the detector must be monitored for many parameters as they can affect both the efficiency and the working life of the detector. The temperature of the gas inside the individual chambers is a critical parameter to be monitored, as it can both affect the efficiency of the detector and point out on-board electronic circuitry overheating. In this paper we propose a novel gas temperature sensing system based on optical fibre technology. The adopted technology is well suited to make distributed sensing systems with large number of sensors, it is immune to electromagnetic disturbances and it has adequate radiation hardness. A prototype of the basic sensor of the proposed system was tested at the experimental facility for Resistive Plate Chamber characterization available at the INFN laboratories in Frascati. Results are presented and discussed.

Keywords: fos; fiber optic sensor; fbg; fiber bragg grating; rpc

1. *E-mail*: michele.caponero@enea.it.

 doi:10.1016/j.phpro.2012.02.400

1. Introduction

Gaseous detectors are widely used in nuclear and subnuclear physics experiments as trackers and muon detectors. In fact all four current major experiments (ALICE, ATLAS, CMS, LHCb) at the Large Hadron Collider of CERN in Geneva, Switzerland use gaseous detectors such as drift chambers, drift tubes, resistive plate chambers, micropattern gaseous detectors. To make such detectors work with optimal performance, it is very important to control the parameters of the gas fluxed in the detector, such as temperature, relative humidity, percentage of components of gas mixture and gas mixture purity. Among gaseous detectors, RPC (Resistive Plate Chambers) are quite difficult to be monitored for their gas parameters as they often have very large overall volume and are made by a large number of small chambers, thus requiring dense distributed monitoring systems.

Dependence of gas parameters and gas mixture composition on performance of Resistive Plate Chamber detectors were long since performed at the Frascati National Laboratories of INFN (Italian National Institute of Nuclear Physics) [1], where a test facility is available in the ASTRA experimental hall. Currently, extended studies are in progress to achieve an efficient real-time monitoring system of gas fluxed through RPC detectors. Experimental work is done using a typical gas mix: 96% of C2H2F4, 3.5% of iC4H10 and 0.5% of SF6; humidity 45% RH. Because of the high cost of freon and the very large volume of RPC detectors currently being used in HEP experiments, the research activity is focused on solving problems related to the development of special filters to purify the gas mix fluxed in closed-loop conduit design[2-4]. Within such activity, we propose to adopt the innovative technology of Fibre Bragg Grating to develop a distributed temperature sensing system based on the use of a large number of sensors inserted in the gas conduit of gaseous detectors. The importance of distributed temperature monitoring of the gas is related to its critical effect on the efficiency of gaseous detectors and to its potential use in feed-back control system of the detector High Voltage polarization circuitry.

Fiber Bragg Grating sensors

FBG (Fiber Bragg Grating) sensors consist in a diffraction grating made by a modulation of the refractive index of the core of an optical fibre [5]. Typically, an FBG sensor consists of a single mode optical fibre with a grating written in a short segment of the core of the optical fibre. The grating is written by exposing the short segment of the fibre to an interference pattern of ultra-violet radiation, produced by either the holographic or the phase mask technique [6]. The bright and dark fringes of the interference pattern induce a permanent modulation of the refractive index of the core. If broad-band light travels along the fibre, it suffers diffraction at the grating and a narrow-band light signal is back-reflected along the fiber. The wavelength of the back-reflected light is determined by the occurrence of the Bragg condition, according to the value of pitch of the grating and to the value of the effective refraction index. If the FBG is strained and/or heated, changes of the value of the pitch and/or the value of the effective refraction index occurs, leading to a change in the Bragg condition and thus in a shift of the wavelength of the back-reflected signal. Thus, an FBG sensor can be used to probe the temperature/strain of a structure to which it has been put in thermal/mechanical contact [7]. Typical resolution for strain measurement is about 1microStrain; typical temperature resolution is about 0.1K in the 200K÷400K range.

Due to the spectroscopic nature of the underlying technology, FBG sensors are immune to electromagnetic interferences and have already been proved to have Radiation Hardness feature that make them suitable for HEP experiments. Moreover, adopting FBG sensor technology can greatly simplify the cabling of distributed sensing systems. In fact, thanks to the spectroscopic nature of the underlying technology, many sensors can be monitored by WDM (Wavelength Division Multiplexing) being connected in-series on a single optical fibre, thus reducing the amount of wiring required for installing a large number of sensors.

Experimental Method

We propose to use an array of FBG sensors inserted in the gas conduit of the gaseous detector to monitor the temperature distribution over the full detector, thus allowing early detection and localisation of local overheating. The choice of FBG sensor technology is mainly due to its insensitivity to electromagnetic interferences and to its Radiation Hardness feature. Moreover, FBG sensors require very simple cabling since tens of them can be connected in-series along a single optical fibre. Such features are quite interesting for applications on large gaseous detectors in HEP experiments, and they turn out to be of extreme interest for applications on large RPC detectors built up by a large number of small chambers. In fact gaseous detectors usually operate at high voltage and in strong electromagnetic fields, with high risk of serious upset for any sensor sensitive to electromagnetic interferences. Furthermore, gaseous detectors usually have large volume, thus the reduction of the number of cables to be wired represents an effective advantage in cabling dense distributed sensing systems.

Two prototypes of the proposed sensor were made. The manufacture of the first prototype is schematically sketched in Fig. 1 :i) the short segment of the optical fibre corresponding to the FBG sensor is inserted in a thin metallic tube, slightly tensioned; ii) the metallic tube is filled with thermally conductive gel; iii) the fibre is centred in the tube and permanently hold in position by glue; iv) the tube is inserted in a gas cross-joint, centred along one arm of the joint and permanently fixed by sealant glue. The manufacture of the second prototype is schematically sketched in Fig. 2 : the manufacture is similar to the one described for the first prototype, but the optical fibre is inserted and fixed loose inside the metallic tube. In the following, the first and the second prototype are referred to as straight-mounted prototype and loose-mounted prototype, respectively.

Different performances can be expected for the two prototypes according to the different tensional state of the FBG sensor. If temperature varies, thermal deformation of the metallic tube will affect the tensional state of the straight-mounted FBG sensors but will not be able to affect the tensional state of the loose-mounted FBG sensor. Recalling that FBG sensors are sensitive to both mechanical and thermal disturbances, both prototypes will feel the direct effect of the temperature variation, but the straight-mounted sensor will also feel the tension variation due to the thermal deformation of the metallic tube. The straight-mounted prototype actually has a higher sensitivity to temperature variation since the two effects add up linearly and have similar magnitude, but its features can suffer the occurrence of creep and plastic deformation of both the glue stopping and the optical fibre itself. The loose-mounted prototype is free from perturbations due to unstable mechanical deformations of the constrains, but mechanical shocks can abruptly modify the geometrical shape of the FBG sensor and consequently its tensional state. The manufacture of the two prototypes was intended to obtain an experimental comparative evaluation of the two designs.

Comparison tests were run in the RPC Test Facility of the ASTRA experimental hall at Frascati National Laboratory of INFN. Fig. 3 shows a sketch of the experimental set-up. The two prototypes were installed in the outlet gas conduit of a RPC detector made of ten single-gap layers. Close to each prototype a reference thermocouple was inserted in the gas conduit to monitor the gas temperature just upstream the prototypes. FBG sensors were monitored by FBG Interrogation System model sm125 by Micron Optics, sampling rate 1Hz, resolution 1pm. The two prototypes were connected in series on a single optical fibre. Thermocouples were monitored by Temperature Logger model NI4350 by National Instruments. FBG sensors used to make prototypes are model OS 1550 by Broptics Technology Inc., with nominal temperature sensitivity 11pm/K and nominal strain sensitivity 1.2nm/microStrain. Fig. 4 shows a picture of the prototypes being prepared to be installed in the RPC gas outlet conduit. Fig. 4a shows one of the two prototypes and the reference thermocouple; Fig. 4b shows the prototypes and the reference thermocouples being mounted in a small plastic box provided with inlet and outlet gas connectors to be inserted in the RPC gas conduit; Fig. 4c shows the box, resting on top of the RPC detector, inserted in the RPC gas conduit during test run.

Experimental Results

Tests were run stopping the precise temperature control system of the hut in which the RPC detector is housed, thus letting the gas temperature be influenced by the roughly controlled room temperature of the experimental hall. Peak to peak temperature variation of about 4°C was normally achieved by night-day temperature cycling; bias temperature value was roughly controlled by modifying the temperature setting of coolers available in the hut.

Fig. 5 and Fig. 6 show representative results of performed test runs. The signal of FBG sensors is given in °C adopting the temperature sensitivity parameters worked out for both prototypes by previous calibration measurements, herein not reported. Plots on top of the pictures refer to the straight-mounted prototype; plots on bottom of the pictures refer to the loose-mounted prototype. Plots on the right hand side of the pictures show FBG vs Thermocouple temperature measurements: in both test runs the straight-mounted prototype achieves the largest dispersion of data. On the left hand side of the pictures the residuals between the measurement made by Thermocouple and by FBG are reported vs Time; in the same plot the temperature values measured by Thermocouple are reported too. It can be observed that in both test runs larger residuals occur in correspondence of larger temperature gradients. That can be due to the relatively large mass of the FBG prototypes, which results in a thermal capacitance larger than the one of the thin thermocouple junction. In Fig. 5 residuals of the straight-mounted prototype show a trend to larger mean values as Time increases, whereas such trend is not present for residuals of the loose-mounted prototype. In Fig. 6 residuals of the straight-mounted prototype show a variation of the bias value much larger than the one occurring for the residuals of the loose-mounted prototype.

The overall evaluation of the comparative tests shows that the loose-mounted prototype has the best performance; that should depend on the uncoupling from the thermally induced mechanical deformations of the housing metallic tube.

Conclusions

Results show that some improvement is required in order to succeed in reaching the goal of ±0.05°C precision. A new housing design has been planned and will be tested in future work. Moreover, development of a custom tubing joint with special openings for the FBG sensor is in progress, aiming at the development of an industrial-grade prototype suitable for installation on large in-service gaseous chamber detectors.

References

[1] R. Santonico et al., “Development Of Resistive Plate Counters”, Nucl. Instrum. Meth. 187 (1981) 377.

[2] M. Abbrescia et al., “Gas analysis and monitoring systems for the RPC detector of CMS at LHC,” LNF-06-34-P, LNF-04-25-P, Jan 2007. 9pp. Presented by S. Bianco on behalf of the CMS RPC Collaboration at the 2006 IEEE Nuclear Science Symposium (NSS), Medical Imaging Conference (MIC) and 15th International Room Temperature Semiconductor DetectorWorkshop, San Diego, California, 29 Oct - 4 Nov 2006. arXiv:physics/0701014.

[3] L. Benussi et al., “The CMS RPC gas gain monitoring system: an overview and preliminary results”, Nucl. Instrum. Meth. A 602 (2009) 805 [arXiv:0812.1108 [physics.ins-det]].

[4] L. Benussi et al., JINST 4 (2009) P08006 [arXiv:0812.1710 [physics.ins-det].

[5] *K.O. Hill, G. Meltz,* FIBRE BRAGG GRATING TECHNOLOGY FUNDAMENTALS AND OVERVIEW – Journal of Lightwave Technology 15 (1997).

[6] *I. Bennion, J.A.R. Williams, L. Zhang, K. Sugden, N.J. Doran,* UV WRITTEN IN-FIBRE BRAGG GRATINGS – Optical and Quantum Electronics 28 (1996).

[7] *Y.J. Rao,* IN-FIBRE BRAGG GRATING SENSORS – Measurement Science and Technology 8 (1997).

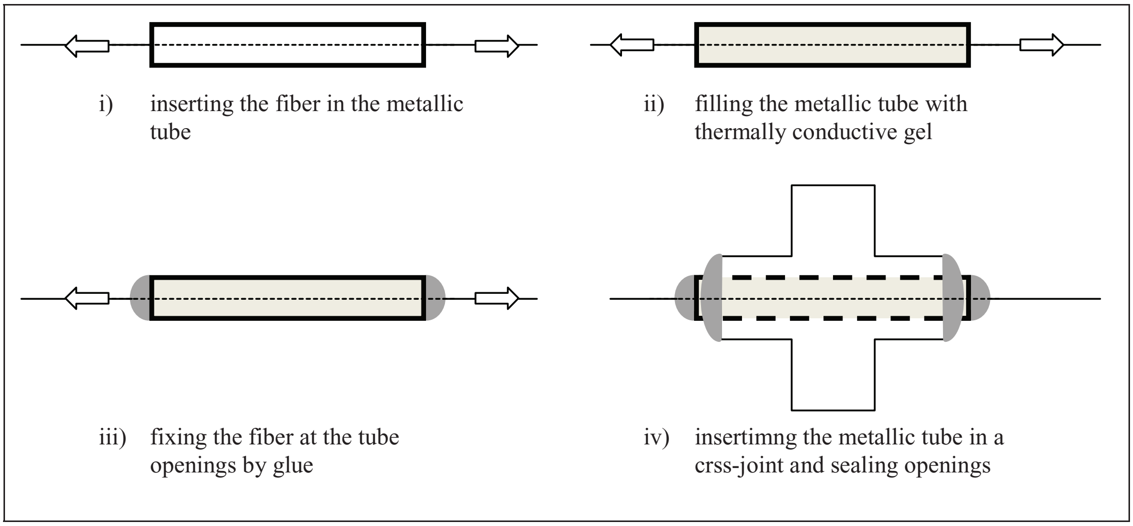


Fig. 1. Production design of the straight-mounted prototype.

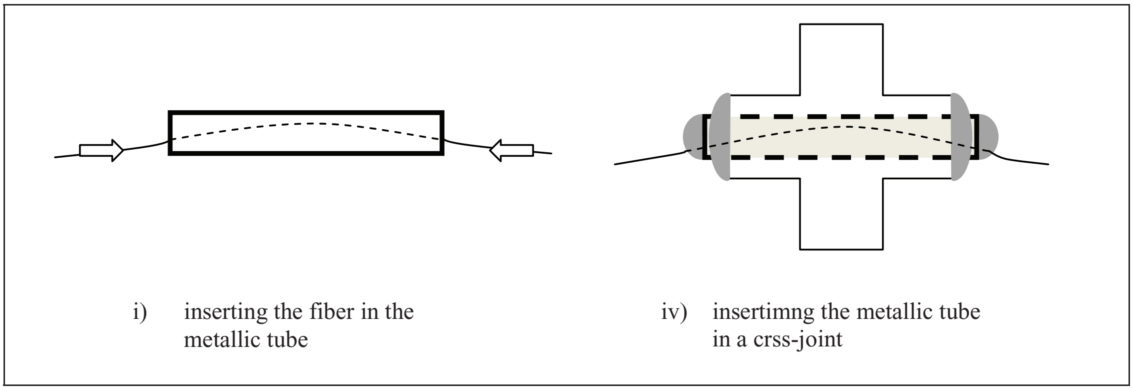


Fig. 2. Production design of the loose-mounted prototype.

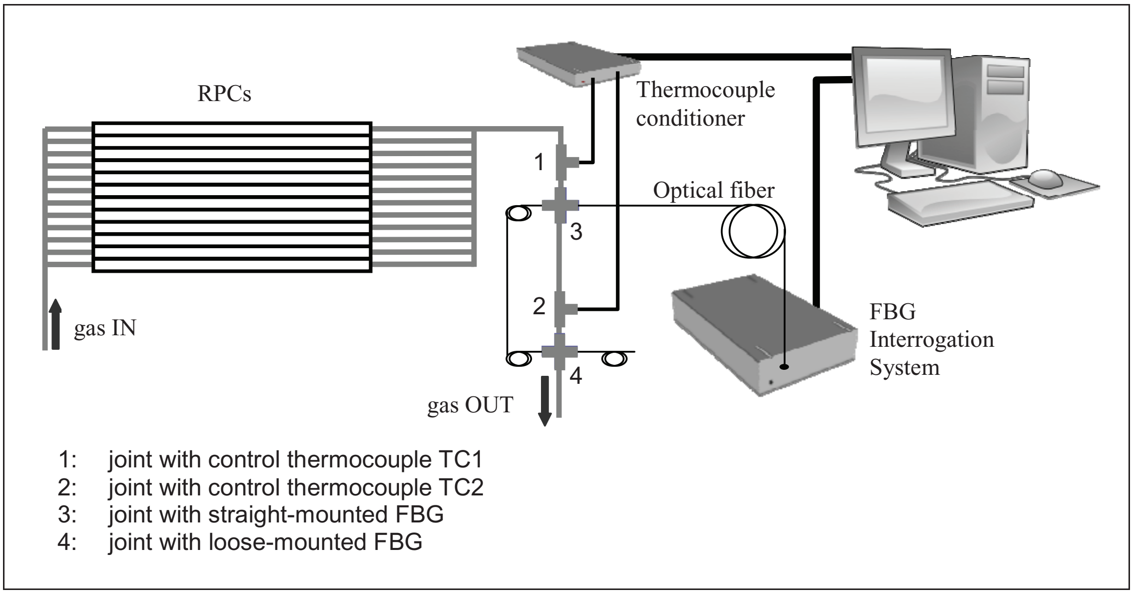
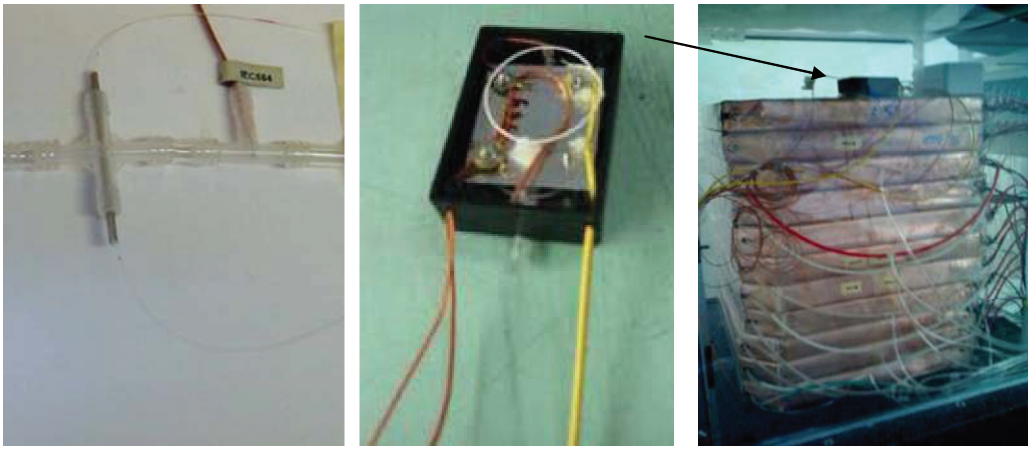


Fig. 3. Sketch of the experimental set-up.



a) FBG sensor prototype and reference thermocouple

b) FBG sensor and reference thermocouple mounted in compact box

c) Box housing prototypes inserted in RPC gas conduit during test run

Fig. 4. (a) Prototype provided with the its reference thermocouple; (b) Prototypes and reference thermocouples mounted in compact box; (c) Box with prototypes and thermocouples inserted RPC gas conduit during test run.

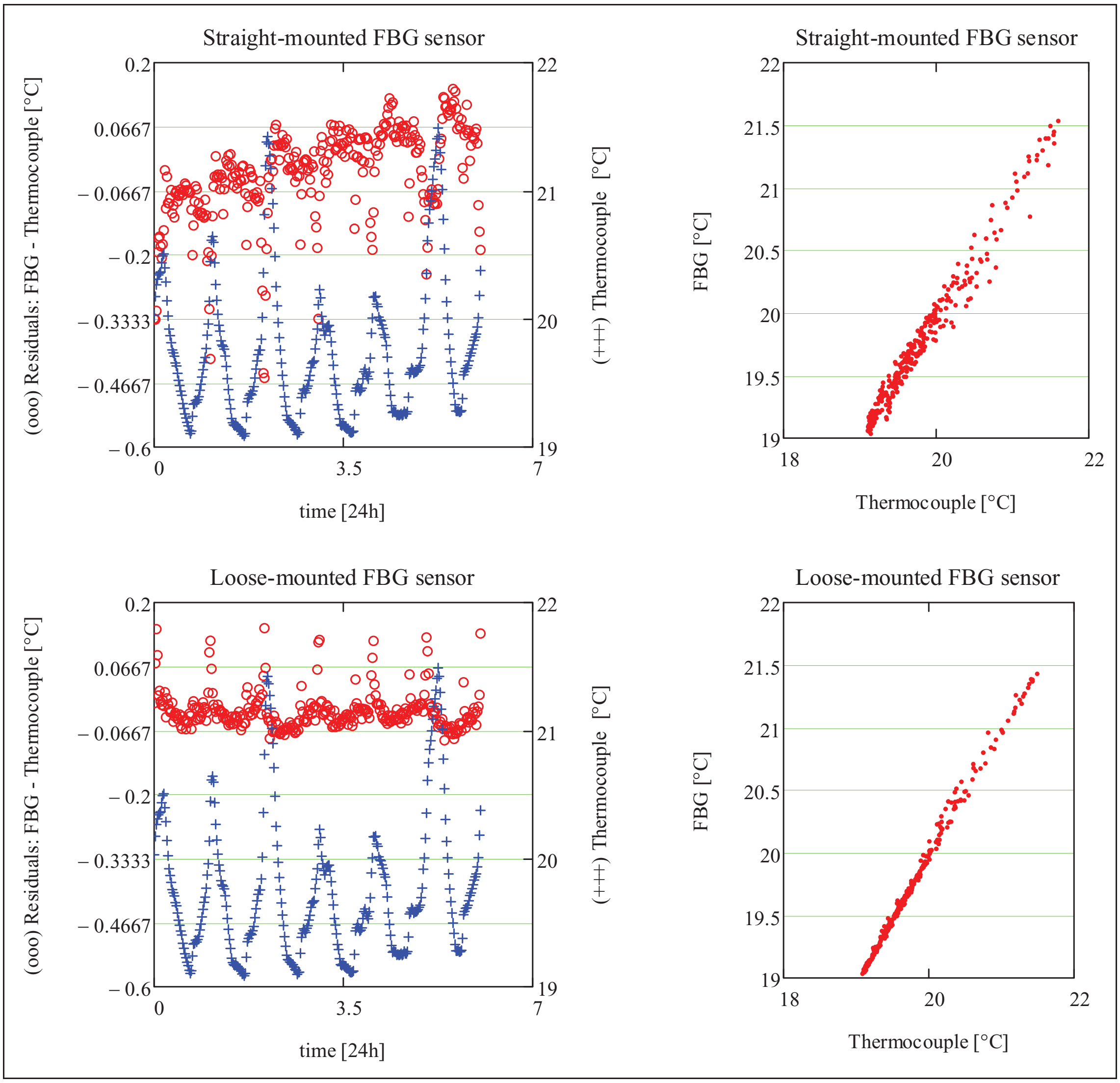


Fig. 5. Results from 7-days test run.

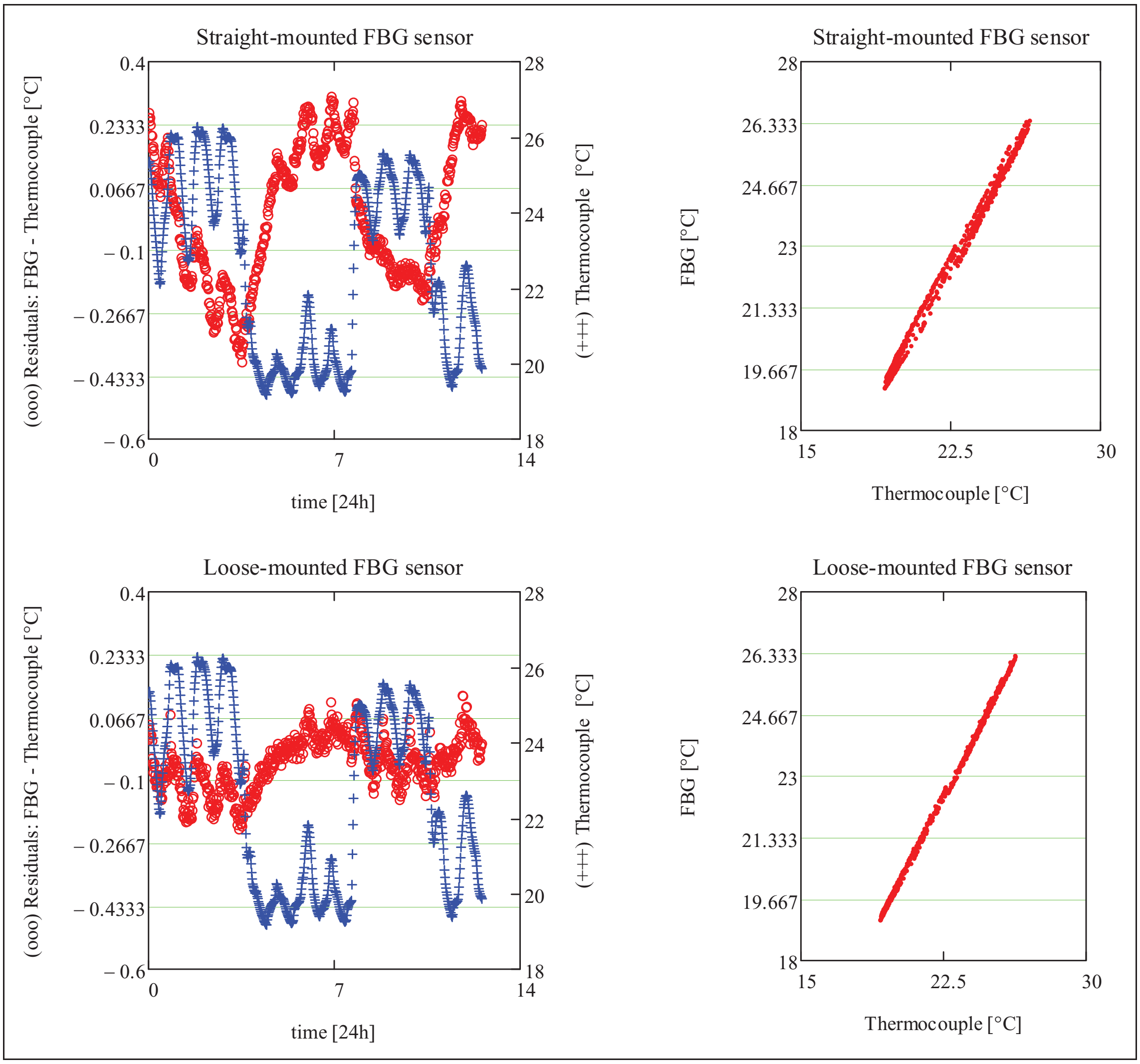


Fig. 6. Results from 14-days test run.